Instructional strategies to promote conceptual change about force and motion: A review of the literature

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Abstract. During the last four decades, the results of a great deal of research have indicated that, prior to any formal instruction in physics, students hold scientifically incorrect ideas about physics concepts in general, and about the force and motion concepts in particular, the latter being considered central in science teaching. To these days, students' conceptual difficulties in mechanics have been well documented and a considerable body of research literature in science education has been formed.
In the present study we first review briefly most commonly encountered students' alternative conceptions and mental barriers in school mechanics. Subsequently, we present teaching approaches that attempt to confront the aforementioned difficulties in students' thinking. Ultimately, with respect to the studies presented, we attempt to highlight potentially effective characteristics of learning environments and strategies suitable for the promotion of conceptual change in school mechanics.

Keywords: alternative conceptions, force and motion, mechanics, conceptual change

Introduction

For many years now, a plethora of studies have been documenting the importance of prior knowledge, ideas, or preconceptions students hold towards certain concepts and physical quantities considered central in science teaching and understanding. In the present study, we focus on persisting ideas and preconceptions on the concept of force and its effects on motion. Firstly, we concisely present most typical preconceptions and mental barriers in the field of interest as they have been highlighted by a considerable amount of research. Subsequently, we review literature in order to trace and present teaching approaches that attempt to confront the aforementioned conceptual barriers and alternative conceptions in students' thinking, relative to force-and-motion concepts. Eventually, with respect to the studies presented, we attempt to discern and accentuate certain generic characteristics of a potentially effective learning strategy towards conceptual progress in force and motion; we hope that these highlighted features and aspects of instruction could serve as a reference while planning a teaching strategy in a school context, to face the matters of concern.

Method

To achieve the purpose of this article we sought empirical studies, theoretical papers as well as conference papers that i) address the issue of conceptual change in mechanics and ii) introduce certain approaches targeting the improvement of students' scientific learning of force and motion. To highlight alternative conceptions and mental barriers in students' thinking relative to force and motion, we searched in the databases of ERIC, Scopus, and Teacher Reference Center and used the following query: (preconceptions OR "prior ideas" OR misconceptions) AND (force OR "Newton's Laws"). This search resulted in a total of 136 publications. We then run through the articles and further filtered search results according to relevance, which resulted in a total of 24 articles, in addition to another 10 publications from the authors' literature records, a total of 34 publications. To identify instructional approaches for conceptual change on force and motion, peer-reviewed articles and book chapters published from January 1997 to January 2016 were included in our literature search. We searched in the databases of ERIC, Scopus, Teacher Reference Center and chose the following queries: "conceptual change" AND (force/"force and motion" OR/AND "Newton's laws") which resulted in a total of 125 citations from the aforementioned databases, in addition to another 3 articles distinguished according to relevance from the authors' literature records. We then read the articles and further filtered search results according to the following criteria:

- A specific teaching approach towards conceptual understanding in force-and-motion related concepts was explicitly introduced and tested in the work presented.
- The proposed approach demonstrated an aspect of originality with respect to traditional teaching methods.
- The proposed approach was applicable in formal school settings.

Ultimately, 7 cases were chosen to be extensively presented in this paper, selected under the prism of introducing a diversity of approaches with respect to the research methods, tools and findings.

Theoretical Research Framework

The importance of mechanics in formal science teaching

Classical Mechanics plays a key role among physics domains. Firstly, from an epistemological perspective, mechanics is considered essential in structuring other important physics domains, such as heat and electricity. In school science, conceptual understanding of force and its effects on motion are a prerequisite to students' acquiring further understanding on other instruction units of the physics curricula, such as electricity, waves, etc. (Carson & Rowlands, 2005; Galili, 1995). To this respect, understanding the force and motion domain in physics may be regarded as a presupposition of understanding physics as a whole. On the other hand, phenomena involving force and motion are ubiquitous in everyday life and constantly affect children. Evidently, students are not familiar with the formal physics involved; they are only familiar with certain everyday life phenomena for which they intuitively form some sort of explanations or predictions. These prior ideas or alternative conceptions that students develop from an early age relative to these phenomena usually serve them well in providing satisfying interpretations and predictions of motion in the world. Yet, although students are familiar with the phenomenological experience of force and motion concepts in action (Bruun & Christiansen, 2014) their reasoning is intuitive, context dependent and, thus, most often it fails to align with formal physics conceptions. With reference to relevant research, it actually turns out that this phenomenological experience constitutes the main constraint in the acquisition of students' scientific knowledge in mechanics of bodies at rest and in motion and one of the reasons that these ideas are being reported as strongly resistant to change.

To these days, after almost four decades of research on probing students' understanding of natural phenomena (White & Gunstone, 2008), students' conceptual difficulties in mechanics have been well documented and a considerable body of research literature in science education has been formed, regarding students' alternative conceptions in classical mechanics (Rowlands et al., 2007; Driver et al., 1994; Halloun & Hestenes, 1985; Champagne et al., 1980; Trowbridge & McDermott, 1980; 1981).

Students' prior ideas relative to the concept of force

In particular, the concept of force, which is considered central in mechanics, has been the subject of a plethora of studies for many years now (Halim et al., 2014; Kariotoglou, Spyrtou & Tselfes, 2009; Demirci, 2005; Jimoyiannis & Komis, 2003; Thornton & Sokoloff, 1998; Hestenes, 1992).

In Newtonian Physics, force is not an internal property of objects but a process used to explain changes in the kinematic state of objects, either moving or at rest (Vosniadou et al., 2001). Yet, this scientific view is far from the models formed by children based on their everyday experience of bodies in motion. When it comes to bodies at rest, students often fail to identify forces exerted on those bodies (Minstrel, 1982). For bodies in motion, the Aristotelian idea that in order to keep an object in motion, a continuous action of a force is necessary has been extensively studied in literature as an idea that is most popular (Watts & Zylbersztajn, 1981) and most persistent (Clement, 1982) among students of all ages.

Young children tend to construct an initial concept of force according to which force is a property of objects relating to their heaviness and they use this idea to explain the capacity of a body to react when it contacts with another object, also reported in literature as the "Dominance Theory" (Hestenes, 1992). Later on, when they start to differentiate between animate and inanimate bodies they tend to assume, upon observation of inanimate objects and ignoring the existence of friction or air-resistance, that the natural state of inanimate objects is that of being at rest. As a result, they tend to explain motion as a state produced by some sort of external agent that, upon contact, carries rather than exerts a force on the object, and that this force gradually dissipates as the object's motion evolves (also reported in literature as the "Impetus" alternative conception). As a consequence to this idea, students also tend to confuse the conceptions of force and energy. This Aristotelian idea that a continuous force is necessary to keep an object in motion often predominates among students (Atasoy et al., 2011; Driver et al., 1994; Halloun & Hestenes, 1985) who incline to establish a linear representation between the magnitude of force on an object and its speed and tend to believe that acceleration is due to increasing force (Halloun & Hestenes, 1985).

Students' conceptual barriers relative to school mechanics

Regarding school physics, the major concepts of classical mechanics (kinematics and dynamics) are displacement, velocity, acceleration, force and momentum. The concept of energy (kinetic, potential energy and work) is shared between mechanics and other physics' domains. School Mechanics is governed by Newton's three laws, in trivialized versions, similar to the following (Duit, Niedderer & Schecker, 2007): i) if there are no forces acting on a body, it remains in its state of motion—at rest or with uniform velocity ("inertia"); ii) the (resultant) force acting on a body is proportional to the body's mass and acceleration (F=m*a); iii) to each force exerted on a body ("action"), there is an equal but opposite force ("reaction").

In addition, free falling of objects and circular motion as Newtonian contexts seem to present students with several conceptual barriers (Keeley & Harrington, 1994). Furthermore, in student understanding, gravity and friction as well as mass and the distinction between mass and weight are also reported as fundamental in their conceptual progress in mechanics (Driver et al., 1994). Ultimately, understanding of the free-body diagram that constitutes a very important problem-solving tool in high-school instruction of mechanics presupposes understanding of vectors; this knowledge will enable the full immersion of students in more composite Newtonian concepts of objects under the influence of many forces, or multiple objects interacting. Being able to study these multiple contexts will potentially help students gain a deeper understanding on force and motion (Keeley & Harrington, 1994).

As stated earlier, the most dominant alternative conceptions in force and motion have been highlighted as the outcome of a considerable amount of research. Among others, Gilbert and Watts summarized the general conclusions that can be derived from the alternative conceptions' studies as follows (Gilbert & Watts, 1982): i) if a body is not moving there is no force acting on it, ii) if a body is moving there is a force acting in the direction of the motion and iii) constant motion requires constant force. Similarly, Driver et al. (1994, p. 149) have identified the following main ideas, based on research findings about students' ideas on force and motion:

- if there is no motion, then there is no force acting
- there cannot be a force without motion
- when an object is moving, there is a force in the direction of its motion
- a moving object stops when its force is used up
- a moving object has a force within it which keeps it going
- motion is proportional to the force acting
- a constant speed results from a constant force

Apart from the above, well documented and common across contexts ideas in students' reasoning, confronting students with approaches that aim to elicit their ideas prior to instruction may always bring to surface ideas more specific and subtle in meaning, relative to the studied concepts.

Tools for diagnosing students' alternative conceptions and evaluating students' conceptual progress on force and motion concepts

To bring out students' understanding and evaluate conceptual progress in mechanics, diagnostic instruments in the form of tests are administered, usually in identical form, right before (pre-test), right after (post-test) and sometimes a few weeks or months after formal instruction of the relevant lesson units. Among studies conducted with the aim to evoke and/or measure conceptual understanding of students relative to force and motion concepts, the Force Concept Inventory, FCI (Hestenes et al., 1992) the Force-Motion Concept Evaluation, FMCE (Thornton & Sokoloff, 1998) and the Mechanics Baseline Test, MBT (Hestenes & Wells, 1992b), have been used widely as popular standardized multiple-choice diagnostic tools. Often enough, in-depth interviews with selected students are also being conducted and videotaped (Vosniadou et al., 2001); in addition, instructional units may also be videotaped (Duit, Treagust & Widodo, 2008; Vosniadou et al., 2001) and dialogues both among students and students and teachers may be transcripted and analyzed (Vosniadou et al., 2001), to aid at forming a better understanding on the process of the cognitive change. To this purpose, Interviews-about-instances, as described by Osborn & Gilbert (1980), have also been used (Atasoy et al., 2011) as a method to explore students' pre- and post- instruction ideas on force and motion.

Teaching strategies

Relevant literature provides adequate evidence that, in general, conceptual change instructional approaches have better learning outcomes when compared to traditional approaches of teaching (Duit, Treagust & Widodo, 2008). The benefits arising from such methods are further supported when the instructional design of the learning environment combines various constructivist principles of teaching and learning.

The case of an experimental learning environment

Vosniadou et al. (2001) attempted to construct a learning environment for teaching mechanics to fifth- and sixth-grade students in Greece. The study has been a part of a larger project whose purpose was to develop and test learning environments to promote the learning of science in elementary school; an effort has been made to leverage the results of prior research on the development of the concept of force and, at the same time, to exploit research-based principles: active processing of information, situated learning in real-word contexts, individual learning based on each child's strengths and weaknesses, giving rise to meta-conceptual awareness and construction of explanatory frameworks with greater, systematicity, coherence, and explanatory power. According to the researchers, the experimental curriculum was designed to help students develop distinct and well differentiated concepts of force and energy.

The mechanics course lasted for a period of 8 weeks (8 lesson units, 90 minutes each). 25 students participated in the experiment, working together in small groups of five. The students participated in hands-on experiments during which measurements of the magnitude of various forces were taken. Students were also engaged in constructing and using their own dynamometer, in an effort to form a deeper understanding of the scientific concept of force, as the measurable interaction between two bodies, rather than thinking of force as a property of physical objects. For this purpose, they also used symbolic representations of force and energy. Vectors were introduced both in commonly used graphical representations as well as three-dimensional objects made of cardboard to represent forces exerted on real, three-dimensional objects. For the same reason, small yellow stickers were used to represent energy units. The stickers were attached to a piece of cardboard to represent objects' energy deposits and were transferred from the energy deposit of one object to the energy deposit of another object in order to represent energy transfer. Lastly, a "friction model" was constructed out of cardboard to represent, in magnification, the anomalies of the contact surface between a moving object (e.g. a brick) and a supporting object (e.g. table).

The results of this research demonstrated a significant increase of scientifically consistent responses among students having attended the intervention (experimental group) as opposed to students having received traditional instruction (control group) who showed little or no conceptual progress. Based on the findings of this study, the researchers particularly stress the value of explanation to others in the context of a classroom as a mechanism for extending the benefits of self-explanation and promoting understanding and conceptual change. Teachers have been found to hold a key role in this learning procedure: instead of simply presenting the scientific model they are urged to devise strategies for bringing to surface students' prior beliefs and then to utilize these ideas as the basis for dialogue and "negotiation of meaning" that is, according to the authors, necessary to foster the deeper understanding required for conceptual change.

An inversed, logical-thinking approach to teach Newton's law of motion using deductive explanation tasks (DETs)

Lee and Park (2013) attempted to investigate the effectiveness of applying Newton's second Law in physics problems by inversing the traditional teaching process. In their work, the authors adopt an approach based on deductive thinking on scientific information. Under this scope, they propose an inversion of the traditional teaching process of Newton's law of motion in school according to which the forces acting on an object are presented at first; instead, they ask students to identify the net force on a given object by observing the change in the object's motion. To this purpose, they develop deductive explanation tasks (DETs) based on the D–N model of scientific explanation of Park & Han (2002) involving various examples of an object's motion. Tests conducted on the effectiveness of the DETs by comparing students' conceptual understanding before and after applying the DETs as well as comparing students' achievement of an experimental group (64 11th grade students) with a control group (72 11th grade students) have demonstrated that the deductive logical explanation for identifying forces from the change of motion could be useful in improving students' conceptual understanding and could help learners improve their attitude towards physics learning in general. Based on the findings of their research, the authors stress that, in some cases, students' weakness towards conceptual change is due to the lack of certain more general skills, strategies and pieces of knowledge such as low understanding of scientific words used in a scientific context, inability to correctly and efficiently decode written physics texts, unfamiliarity with the application of scientific explanations in a real situation as well as knowledge gaps such as the arrow representation of the direction vector.

Embodied demonstration and animation as means of improving students' ability to draw arrow forces

Halim et al. (2014) focused on the arrow representation of forces and its potential to facilitate students' understanding of basic force concepts. In light of this, they have performed an intervention based on active learning which has been proven effective according to the results of the study. The action research has been carried out on 23 sixteen-year-old students in Selangor, Malaysia.

The intervention itself consisted of introducing the basic concepts of force, such as "contact force" and "field force", emphasizing on their respective arrow representation with differing starting points. Five different situations were investigated in the research, each corresponding to a different situation of forces in equilibrium: A book resting on a table, a man pushing a wall, a skydiver falling at terminal/constant velocity, an airplane moving at constant velocity and a painting hanging on a wall. The teaching methods used to identify and label the forces were demonstration and animation. Analogies in the form of demonstration that engaged students in bodily participation were used for situations i) and ii). For situations iii) and v) animations have been used to represent the objects of interest. The animations have been guided by planned questions to challenge students' thoughts on the situation. For situation iv) an analogy with a ring hanging from a thread and being pulled by a four spring balance has served to simulate the situation of an airplane moving at constant velocity. Changes in the equilibrium state of the ring by means of changing the pairs of opposing forces resulted in motion with constant velocity. Pre-tests as well as post-tests were administered in order to measure the students' ability to draw arrow forces in terms of direction, magnitude, labeling type and starting point.

The test results showed significant improvement in students understanding, thus affirming the positive effects of students' engagement in embodied demonstrations. Another interesting finding was that students demonstrated difficulties in correctly identifying the magnitude of forces exerted on objects in equilibrium. The authors assume that this difficulty is due to the fact that forces are not visible hence estimation of their magnitude requires "formal thinking". To this end, they suggest that emphasis should be given on explicitly stating the force magnitude in each situation by using an appropriate tool such as a spring balance, whenever possible.

An instructional strategy based on kinesthetic activities

In much the same constructivist spirit, a different approach has been proposed by Bruun & Christiansen (2014). According to the authors, recent research has reported significant benefits from the use of kinesthetic learning activities in scientific concepts' understanding. The authors state that "students' misconceptions stem from imprecise conceptual understandings of physical concepts, although they are completely familiar with the phenomenological experience of these concepts in action". To this respect, they argue that systematic incorporation of such familiar everyday-life kinesthetic experiences in physics teaching could serve the formation of conceptual structures more stable across different contexts and better aligned with formal physics compared to those of traditional teaching. In proof of the above, the study adopts the image schema effort-resistance-flow (DiSessa, 1993), as central to teaching mechanics, in order to build a teaching framework based on the Theory of Didactical Situations, TDS (Brousseau, 1997) as a basis for relating students' bodily experiences to the formal Newtonian concept of force. Upper secondary students took part in this teaching unit, in groups of three. The students were presented with certain materials comprising the *didactical variables* (rope, handles, slabs, worksheets) and were asked to perform kinesthetic learning activities while at the same time discussing and noting down i) descriptions of the activities performed, ii) Physics concepts they believed were relevant to these activities and iii) their explanations of how they think these concepts are related to their bodily experiences.

Among other things, the authors highlighted the significance of the teacher's role: focusing on students' explanations, using key points of these explanations to make generalizations and mapping of their ideas to the formal physics language, providing students with guiding questions, validating their reasoning and providing them with in-time explanations. The authors suggest that, in general, most students are able to use such activities to engage with each other in content related discussions and that, students do think of this engagement as positive. The ultimate goal of such an approach would be for students to formulate their knowledge as they are constructing it, by means of experiencing, discussing, drawing and noting down their ideas. In a similar manner, teachers should design experiences that will both enable students reach a higher level of abstraction than the kinesthetic activity itself and relate these experiences to formal physics knowledge.

Confronting prior ideas on force and motion with the aid of computer technology

For many years now, computer simulations have been used as learning tools and in many cases they have been proven far more effective than traditional learning methods in teaching scientific concepts (Hewson, 1985; Novak, Gowin & Johansen, 1983; Thornton & Sokoloff, 1990; 1998). Furthermore the use of multi-dimensional instructional environments contributes to improving students' motivation, whereas visualizing physical and chemical processes, further encourages conceptual understanding (Trindade, Fiolhais & Almeida, 2002). In particular, the perspectives of using computer simulations as a means of confronting students' prior ideas in force and motion have also been the subject of research.

In this spirit, Jimoyiannis, Mikropoulos & Ravanis (2000) have utilized computer simulations to examine the cognitive progress of Greek students regarding the central concepts of velocity and acceleration, also considered fundamental in understanding Newton's Laws. The research has been conducted on a total of 57 students on their first year of upper secondary education in a high school of Ioannina, Greece. The research aimed to identify and study students' most common conceptions on velocity and acceleration. In addition, it examined the effectiveness of computer simulations on students' understanding of these concepts by means of administering pre-tests and post-tests. Most common, according to literature, pre-conceptions in students' thinking have been affirmed by the outcomes of the research, namely, confusion of position and velocity as well as of average and instantaneous velocity and indiscrimination between velocity and acceleration.

In the pre-test phase, students were asked to answer certain questions regarding a set of "tasks-experiments" by means of evaluating, explaining and justifying their responses on simple physical processes concerning the concepts of velocity and acceleration. Fifteen days later and without any in-between instruction the students worked individually on simulations of the tasks under study and eventually they were asked to respond to the same questions in the form of a post-test. The simulation-based experiments were designed with Interactive Physics, a two-dimensional physics laboratory and involved the study of the following situations i) two uniformly moving objects ii) a uniformly moving object and a uniformly decelerating object iii) two uniformly accelerating objects and iv) a ball bouncing on the ground. The research results demonstrated a systematic shift from totally inefficient answers to significantly correct answers thus indicating the potential value of simulation in remedying students' ideas and in fortifying their scientific reasoning. Yet the researchers emphasize on the special and persisting difficulties of students on the concepts of speed and acceleration in the case of non-uniformly moving objects, based on the limited progress of students on the relevant tasks (3 and 4) that, according to the researchers, require higher order reflective thinking. They also stress the importance of teacher-student interaction during the simulation experiments as opposed to the students' limited progression reported while working individually. Lastly, the study affirms students' enthusiasm while engaging in simulations, a feature that builds on their positive attitude towards the subject of study.

Likewise, Tao & Gunstone (1997) conducted a classroom study of grade 10 students of an Australian high-school in Melbourne, using computer-supported instruction, in an attempt to target alternative conceptions on force and motion. The study aimed to investigate the effectiveness of simulation-driven conceptual conflicts in conceptual change and to draw certain conclusions on the change process itself. For the purposes of the research, a suit of three computer simulation programs have been developed; the simulations provided contexts for exploring the effects of force on motion in three different situations: horizontal, linear motion with or without friction targeting the force-of-motion and the motion-implies-force alternative conceptions, linear motion without friction/resistance, also intended to confront the motion-implies-force alternative conception and vertical fall under gravity with or without speed-dependent air resistance concerned with forces on a free-falling object and allowing for explorations of the induced motion. Each simulation has been accompanied by a worksheet consisting of predict-observe-explain (POE) tasks designed to provide conceptual conflicts. 27 students participated in the study out of which 14 were identified for in-depth case studies. Students spent five sessions on the computer programs in the middle of the physics unit. They were assigned to work in pairs based on the results of a pre-test (pairs were formed by grouping students with either similar or markedly different scores) as well as on friendship patterns. Another five sessions preceded and followed the computer activities, consisting of conventional lessons, lab work with trolley experiments and ticker timers as well as problem solving.

A wide range of data on these students' conception change has been collected as the outcome of this study. To assess individual students' conceptual change a test was administered in identical form to the students, before and after the instruction as well as after five months to those students who chose physics in grade 11. Within-group students' conversations were audiotaped and transcripted. Responses in the worksheets for each computer-based lesson, as well as responses in the tests, field notes on all lessons as well as interviews with some students were conducted shortly after the three tests have also been collected. Likert-type questionnaires have been administered after the computer activities to evaluate the programs' appeal on students. All data collected were analyzed qualitatively and each student's conceptual development was written up as a case study (for 12 out of 14 students). The survey pointed out that conceptual change, regarding the concepts in question, was a slow process. In particular, conceptual change on students evolved through a series of conceptual progressions and regressions in the course of instruction. Stable conceptual change has been achieved on 6 out of 14 students capable of and willing to reflect on the different contexts and identify commonalities across them, either on their own or after being prompted to do so during the interviews. These students actively engaged in the POE tasks and claimed to have found the programs interesting, useful and enjoyable. On the other hand, students who noted little or no conceptual change showed little cognitive commitment to the tasks. Within a given context, conceptual change appeared to be abrupt, with students giving up their prior ideas for the scientific conceptions. Regarding the collaborative mode of learning, peer conflicts provided appeared to be effective in facilitating conceptual change. In addition, co-construction of shared knowledge has also played an important role in developing shared knowledge and understanding. Yet, the research findings revealed that, to achieve conceptual change, each student needs to undergo "personal construction and sense making of new understanding". Overall, the findings of the study indicated that the programs have been very well accepted by students and that "the computer programs may be of use in facilitating conceptual change, when used in a collaborative learning mode, particularly when students are cognitively engaged in the tasks".

A similar study has been carried out by Kim et al. (2005), with the aim to investigate how a series of unrealistic virtual reality simulations affected students' cognitive conflict and conceptual change. For the purposes of this research, the unrealistic simulations allowed students to make predictions on forces exerted on objects in certain contexts, make an appropriate selection based on their prediction and then visually observe the evolution of the motion, according to their selections. The researchers reported that the use of unrealistic simulations on motion-related concepts are able to evoke inner conflicts and are thus helpful in confronting alternative conceptions. Additionally, the use of virtual reality environment increased students' attention and prompted them to be more concentrated on learning and participating in the activities. Among other things, an important finding of this research has been that it is necessary to minimize the number of variables needed to be manipulated in the simulation, in order to avoid student confusion and keep the simulation environment well organized.

Central considerations in planning instruction on force and motion based on key features of the presented strategies

When reflecting on the teaching approaches outlined in this paper, we identify certain issues that emerge from the implementation of the different learning techniques employed with the scope of targeting conceptual progress relative to force and motion in physics teaching. In Table 1 we summarize the instructional strategies presented here. The outcomes of these efforts further amplify the argument that, trying to align students' ideas with formal knowledge relative to force and motion is a very demanding task. In this section we attempt to stress certain key characteristics of the aforementioned approaches that could be put together to potentially maximize the degree of students' conceptual progress in force and motion.

Table 1. Summary of the studies in this review outlining the research context and the key findings

Reference	Research context	Main findings
Vosniadou et al. (2001)	Goal: To leverage prior research results on the development of the force concept. Sample: 25 Greek students of fifth and sixth grade working in groups of five. 8 lesson units, 90 minutes each. Method: • Hands-on experiments to measure the magnitude of various forces. • Construction of dynamometer. • Symbolic representation of forces by means of graphical representations as well as real three-dimensional objects made of cardboard.	• Conceptual progress • Value of explanation to others in the context of the classroom • Teacher's key role in surfacing students' prior ideas and utilizing them as a basis for dialogue.
Lee & Park (2013)	Goal: To investigate the effectiveness of an inversed, deductive approach to teach Newton's law of motion. Sample: 64 11th grade students (experimental group) and 72 11th grade students (control group). Method: Deductive explanation tasks (DETs) wherein students are asked to identify the net force on a given body by observing the change in its motion.	• Conceptual progress due to cognitive conflict originating from students' logical explanations on why objects move in certain ways by means of identifying the net force direction. • Improved attitude towards physics learning. • Indications of students' weaknesses due to low understanding of words in scientific context/ inability to decode physics texts/unfamiliarity with the application of scientific concepts in real situations/ knowledge gaps.
Bruun & Christiansen (2014)	Goal: To study the potential of integrating everyday-life kinesthetic activities in mechanics teaching. Sample: Upper secondary students in groups of three. Method: adoption of the image schema effort-resistance-flow (DiSessa, 1993) to build a teaching framework based on the Theory of Didactical Situations, TDS (Brousseau, 1997) to relate students' bodily experiences of kinesthetic activities to the formal Newtonian concept of force.	• Significance of teacher's role • Students' positive attitude • Indications that kinesthetic activities potentially enable students to construct their own knowledge and reach a higher level of abstraction.

Table 1. (continued)

Reference	Research context	Main findings
Halim, Yong & Meerah (2014)	Goal: To investigate the potential of the arrow representation of forces to facilitate understanding of basic force concepts. Sample: 26 sixteen year old Malaysian students Method: Different situations of forces in equilibrium have been studied by means of animation or demonstration.	• Improvement in students' understanding • Positive effects of students' engagement in embodied demonstrations. • Indications of difficulties in identifying the magnitude of forces possibly due to forces' invisibility.
	Approaches based on computer simulations	
Jimoyiannis, Mikropoulos & Ravanis (2000)	Goal: To examine cognitive progress of students on the concepts of velocity and acceleration. Context: 57 first grade upper secondary Greek students Method: Simulation-based experiments to investigate velocity and acceleration of moving objects.	• Positive effects of simulation-based experiments on students' engagement and conceptual progress. • Indications of persisting difficulties in the cases of non-uniformly moving objects. • Importance of student-teacher interaction during the simulation experiments.
Tao & Gunstone (1997)	Goal: To investigate the effectiveness of simulation-driven conceptual conflicts in conceptual change of force-and-motion related concepts. Sample: 27 Australian grade 10 high-school students in pairs. Method: development of computer simulations to explore the effects of force on the situations of horizontal, linear motion and motion with/without friction accompanied by worksheets consisting of predict-observe-explain tasks.	• Active engagement • Abrupt conceptual change • Positive effects of simulations on students' engagement and conceptual progress. • Positive effects of collaborative learning and co-construction of knowledge.
Kim et al. (2005)	Goal: To investigate the effectiveness of virtual reality simulations regarding the conceptual change on motion-related concepts. Sample: 4 secondary school students, randomly selected. Method: Interactive virtual reality simulations that enable students to predict the type of force exerted on objects in certain contexts and eventually observe the evolution of motion according to their selections.	• Increased students' attention, focus and participation. • Necessity to minimize the number of manipulated variables in the simulation to avoid student confusion.

Central considerations in planning instruction on force and motion

Firstly, in all above teaching approaches, effort has been made to engage students in hands-on activities and observations. In this fashion, students are encouraged i) to bring to surface their personal ideas and explanations relative to forces and their effects on motion ii) to visualize forces on top of real world objects moving or at rest, iii) to explain the observed phenomena in terms of the introduced scientific concepts and iv) to ultimately trace the instructed principles and laws in real world phenomena they either observe or experience in their everyday lives. It turns out that computer simulations are capable of contributing significantly towards this direction. At present, computer portability and user mobility introduce new learning possibilities for dynamic, on the-spot inquiry and learning. Additionally, modern practices relevant to mobile learning are shifting towards hybrid and augmented reality systems; these technologies possess certain features that seem to render them appropriate for the conceptualization of principles and phenomena relative to force and motion (Tomara & Gouscos, 2014).

Perhaps the most dominant feature present in all cases presented here is the effort for intra-context presentation of the instructed concepts. The outcomes of research indicate that, following instruction, students' explanations are often content-dependent and inconsistent across contexts (Jimoyiannis & Komis, 2003). It appears that students encounter stronger and more persisting difficulties in conceiving the same concepts studied in certain contexts, such as the case of acceleration in the context of non-uniform motions (Jimoyiannis, Mikropoulos & Ravanis, 2000).

To potentially maximize the degree of students' context-independent conceptual progress in force and motion, instructors should cater for presenting students with as many different situations of the same underlying principle as possible. To this end, it becomes evident that the teacher's role is crucial in orchestrating appropriate learning scenarios for the instruction of force and motion by means of fine tuning all above parameters, based on the resources at hand, the time available and the scientific background of students, also with respect to their grade level.

Regarding students' engagement in the learning process of force-and-motion, it appears that their weaknesses in understanding textual descriptions of the situations under study as well as vector representations of quantities actually constitute possible causes of discouragement (Lee & Park, 2013; Nieminen et al., 2012). To this end, we believe that instructors should not disregard students' difficulties in understanding and decoding the textual descriptions and explanations of the underlying situations in favor of the mathematical or graphical information.

Furthermore, it is common knowledge that keywords of Mechanics, like the word force itself, as well as the words weight, mass, velocity, acceleration and energy already hold certain meanings in students' everyday life, these meanings being often inadequate and sometimes even incorrect to be used in scientific contexts. Therefore, instructors should initially put an effort in clarifying that everyday words such as force, speed, weight, etc. usually hold different meanings in scientific contexts. In addition, instructors may leverage students' initial explanations of these keywords as the basis for building upon them the scientific explanations and definitions of the physical quantities they represent. Students should first be familiarized with such key-concepts in their scientific context before they start discussing on the ways they are related (mass, weight, speed, velocity and acceleration, work, energy). Distinguishing between weight and mass, distance and displacement, as well as understanding gravity represent such fundamental barriers in students' understanding in mechanics (Keeley & Harington, 2010). This applies mostly to higher-grade students who have already come across these knowledge elements in earlier grades, before they are instructed the scientific formulas that mathematically express the relations among them, particularly Newton's Laws. It is, therefore, important for instructors to ensure that students will actually be capable of identifying differences between the everyday-life meaning of the words used to refer to the above concepts and their respective scientific meaning through instruction (Vosniadou et al., 2001). In favor of this, and as is the case in most of the presented strategies, students should be encouraged to express their ideas and to formulate their observations and conclusions verbally and/or in writing. In such ways, students further establish their conceptual progress as they shift from mere understanding to leveraging the appropriate scientific "vocabulary" to provide meaningful explanations of the investigated phenomena.

To this respect, we also believe that instructors should pay special attention to the chronological order with which these knowledge elements have been introduced to students in the past (Tiberghien, Vince & Gaidioz, 2009; Vosniadou et al., 2001) and to plan their instruction accordingly, with respect to the students' grade level. Under this line of thinking, Carson & Rowlands (2005) propose the treatment of force before the instruction of acceleration (as well as velocity and displacement). The researchers argue that "to young pupils acceleration can be grasped as the change in motion due to the action of an impressed force." Similarly, Osborne (1980; 1985) stresses that pupils need to grasp the concept of force before they come to thinking about energy or power.

Students' collaborative participation in carefully designed activities also seems to be important in students' escalating conceptual understanding on force and motion concepts.

Students' collaboration may even be further expanded as proposed in (Kocakülah, 2010). In this study, a group of pre-service primary science teacher students participated in the design of a rubric, eventually used for peer-evaluation of their performance in Newton's laws of motion. This approach could be properly customized for a school context to engage students in a rubric design for peer-student evaluation on force and motion concepts, by means of active participation and discussion.

Yet another issue for instructors to consider, particularly when teaching dynamics to upper grades, is the perspective of presenting students with the mathematical formulas of Newton's Laws prior to engaging them in constructivist activities (Hestenes, 1992; Carson & Rowlands, 2005). As opposed to this approach, instructors may directly guide students to focus on activities and observations in an effort to raise conceptual understanding before introducing the mathematical representations of the observed phenomena (McKittrick, Mulhall & Gunstone, 1999).

As mentioned earlier, another important aspect in teaching force and motion is the utilization of the vector representation of forces on a free-body diagram of a body moving or at rest. Since forces as well as velocity and acceleration are essentially invisible, vector representation of these quantities enables their visualization and may assist students to conceive their direction with respect to the direction of motion as well as to estimate the forces' relative magnitude. Therefore, we suggest that students should be encouraged to construct and utilize free-body diagrams during instruction of force-and-motion concepts. This approach may help them reveal the interactions of a given body with other parts of a system, to identify and represent forces as vectors and eventually to describe the type of the body's motion. In favor of this, the utilization of virtual and augmented reality technologies appears to provide a framework suitable for achieving simultaneous multiple representations of the situations under study (Mikropoulos & Natsis, 2011).

Ultimately, it might be of value for instructors to keep in mind (Hestenes, 1992) the chronological order of scientific achievements that enabled Newton's Laws to be conceived. Although current research does not accept the similarity of students' prior ideas as analogous to historical theories and conceptual progress in physics (Brown & Hammer, 2008), we argue that, in certain cases, it might be profitable to confront students with historic questions linked with certain situations in mechanics. In this way, students will be directed towards the realization that the laws of motion are not universal truths hiding in real world phenomena and waiting there for years to be discovered; rather, they were conceived to describe and explain certain regularities in the motion of objects and their conception would not have been possible without a sequence of prior conceptual inventions (Hestenes, 1992). According to Carson and Rowlands 'There are many historical examples in mechanics that can serve to contextualize, for the student, their intuitive notions and to understand fundamentally what science is – that is, to understand the intricate relationship between what is given empirically by Nature, what is derived logically from reason and what has been contributed by the artistic genius of some scientist in the form of a strategic 'convention' of thought (a formula, a model, an idealization, an analogy, a metaphor or some other conceptual heuristics)' (Carson & Rowlands, 2005).

Concluding Remarks

No doubt that the most efficient scenario for trying to achieve conceptual progress in force and motion would be the one that would be able to trigger as many different situations of the underlying theory as possible, in as little time as possible, since classroom time always matters, while at the same time keeping students motivated and engaged. Needless to say the instructor holds a key-role in this process. We argue that further research is needed with the scope of targeting particularly at ways to achieve stable and consistent conceptual progress across contexts in school practice, relative to the concept of force and its effects on the motion of objects. Simulations as well as properly designed virtual or augmented reality environments may be of valuable aid towards this direction.

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